Bull. Org. mond Santé
Bull. Wld Hlth Org. } 1958, **18**, 819-832

THE ECOLOGY OF *AUSTRALORBIS GLABRATUS* IN PUERTO RICO

HAROLD W. HARRY
Ecologist, Department of Medical Zoology,
Walter Reed Army Institute of Research, Washington, D.C., USA

DAVID V. ALDRICH
Microbiologist
US Fish and Wildlife Service, Galveston, Texas, USA

SYNOPSIS

Variations in the distribution of the water-snail *Australorbis glabratus*, intermediate host of *Schistosoma mansoni*, have been studied in Puerto Rico, and an attempt made to correlate the distribution with environmental factors. The main sources of bilharziasis infection are flowing waters, but the evidence indicates that the snail is not found in fast-flowing, high-gradient reaches with falls of more than 20 metres per kilometre. The influence of physiographical features on stream gradient is examined and these findings correlated with the biota, water chemistry and human use of the stream. The alluvial areas of the island have many habitats favourable to *A. glabratus* and constitute the major foci for the transmission of bilharziasis. In general, artificial reservoirs and puddles do not appear to be suitable habitats for the snail. The numerous sink ponds in the Tertiary limestone area on the north coast contain the snail, yet the area is relatively free from bilharziasis, possibly because the ponds are little used.

Although the size of *A. glabratus* populations is limited by many natural enemies, no organism has been found which could be deemed useful for artificial control. Some migratory birds, insects and amphibians may aid the dispersal of the snail. There are indications that the ionic composition of the water may be an important factor in limiting the distribution of *A. glabratus*. It is suggested that large amounts of carbonates and bicarbonates relative to the amounts of chlorides and sulfates may account for the absence of the snail from some habitats (e.g., limestone streams) and that copper and zinc may be limiting agents in some waters containing small amounts of dissolved solids. Concentrations of 0.050-0.100 p.p.m. of zinc, copper, cadmium or silver in distilled water produce a distress syndrome in the snails, and concentrations of more than 1.0 p.p.m. are rapidly fatal in most cases.

In Puerto Rico the distribution of the snail *Australorbis glabratus*, intermediate host of *Schistosoma mansoni*, is irregular. Consequently, the incidence of bilharziasis varies greatly in different parts of the island. Reports on the incidence of this disease are often given on the basis of political divisions. These arbitrary units have little relation to the natural regions of the area. In the present study an attempt has been made to correlate the distribution of the snail with environmental factors. For this purpose, it was essential to compare as large a variety of situations as possible, both in areas where the snail exists, and in those where it is absent.

Correlation of Types of Freshwater Habitat with the Physiography of Puerto Rico

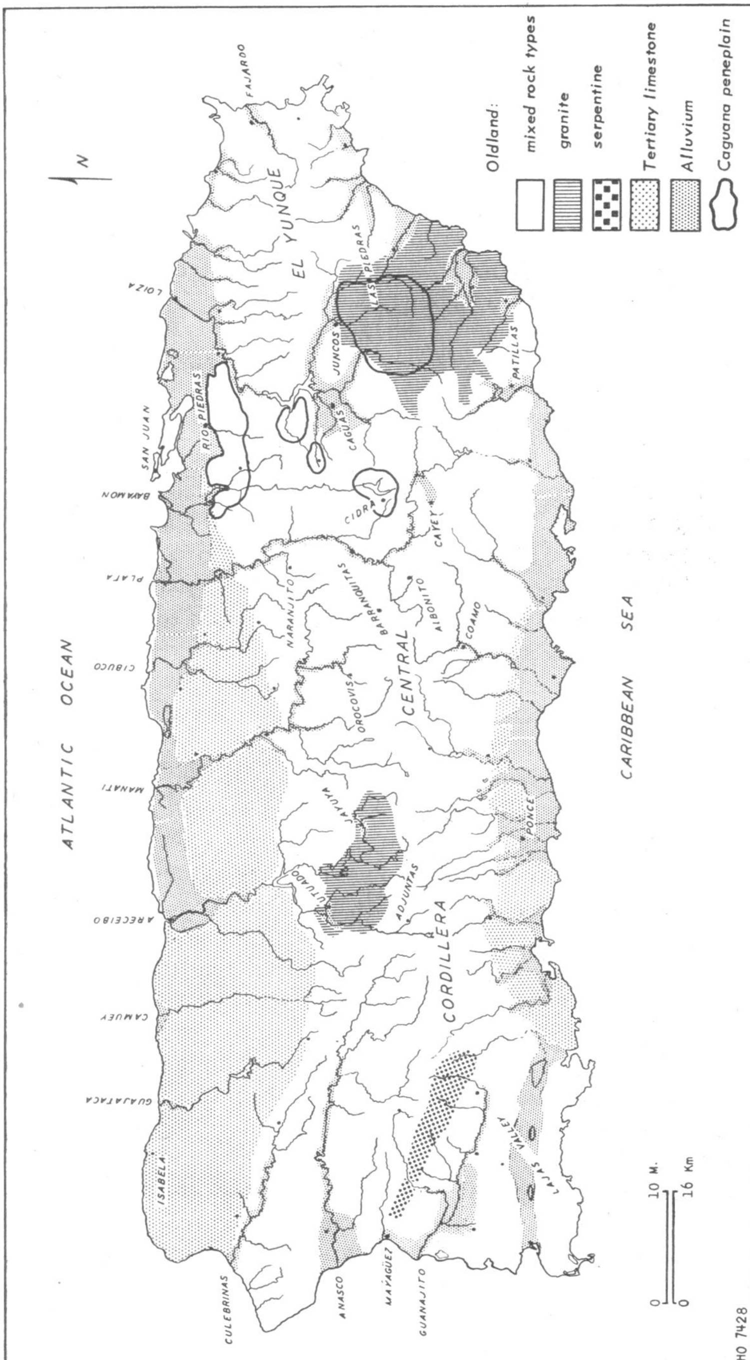
Variations in rainfall and temperature, together with the slope of the terrain and type of bedrock, produce three major physiographical regions in Puerto Rico : (1) Cretaceous oldland province, (2) Tertiary limestone province, and (3) Quaternary alluvial province. Each has distinctive types of freshwater habitat. As this correlation has been described in detail elsewhere (Harry & Cumbie, 1956 a) a brief outline of its more significant aspects will suffice for present purposes.

The average monthly temperature varies from 19-23°C in the higher mountains (El Yunque, see map) to 25-28°C in the coastal regions. Trade winds, coming from the north-east, are the source of the island's rainfall. Along the highest mountain range, the Cordillera Central and El Yunque, the average fall is 100-200 inches (about 2500-5000 mm) annually. Almost all the area north and east of these land masses receives more than 70 inches (1750 mm) of rainfall a year, but the south coast, on the leeward side, receives less than 60 inches (1550 mm) a year. The rainfall exhibits a small peak in May, and a major peak from August to December.

The Cretaceous oldland province consists of well-indurated volcanic and plutonic igneous rocks, with a few small areas of shales, limestones and serpentine. These rock types usually alternate within a few hundred metres in any direction, and over most of the oldland province no single rock type predominates. However, there are two major areas of granite and one of serpentine which are sufficiently extensive to affect the type of freshwater habitat associated with them.

Two peneplain surfaces are evident in this province. The upper, or St. John Peneplain, slopes gently from 1600 feet (500 m) elevation in the east to 3000 feet (1000 m) in the west. It constitutes the skyline of most of the island, but is exceeded in elevation by a range of monadnocks along its leeward margin (the Cordillera Central). The original surface of this peneplain has been almost destroyed by erosion, and is now evidenced only by the co-ordinate heights of the ridges which separate the many streams.

GEOLOGICAL MAP OF PUERTO RICO



Many of the smaller areas of plutonic rocks, upland alluvial valleys and Caguana Peneplain have been omitted.

Several hundred feet below the St. John Peneplain is a second erosional surface, the Caguana Peneplain. In the north-eastern part of the island there are isolated but moderately extensive areas where this surface is more or less intact.

Throughout the oldland province the terrain is so precipitous and the geological history has been such that streams are the only naturally occurring freshwater habitats. Because of the high rainfall, which is well distributed throughout the year, these streams are permanent, except in their extreme headwater areas. Where the St. John Peneplain is the dominating feature, the smaller streams have a high gradient, and are free from established populations of *Australorbis* in the main channel. Where the Caguana Peneplain is extensive, streams are of low gradient, and often contain established populations of *Australorbis*.

In streams derived from mixed volcanic rock types, the headwater reaches flow on bedrock, with large, angular boulders present farther down, and rounded, conglomerate boulders paving the stream-bed in the alluvial province (see below), or where the stream passes through areas of the Caguana Peneplain. These conglomerate boulders give the stream irregular margins that produce quiet areas where *Australorbis* may flourish.

The major areas of granite have been less resistant to erosion than most rocks of this province. Some of the more extensive developments of the Caguana Peneplain and upland alluviated valleys (see below) are found associated with the granite regions. During erosion, granite shows little tendency to break up into boulders. Instead, the individual crystals of the rock separate and the channels almost immediately below the steep-gradient reaches are lined with coarse sand. During the greater part of the year the sand is in almost continual motion in the larger streams. This grinding substrate is usually unfavourable to the establishment of benthic organisms, such as aquatic plants, snails and insects. Where very low rates of flow occur during the drier seasons, the larger granite streams may develop aquatic vegetation and populations of *A. glabratus*, particularly when these snails occur as established populations in the headwater areas.

A major serpentine area forms a high, narrow ridge in the south-western part of the island (see map). The streams on it have steep gradients and flow mostly on bedrock, with little rubble substrate. They are spring fed, resemble streams on limestone (see below) and are apparently free from *Australorbis*.

Two types of artificial freshwater habitat are present in the oldland province. By damming streams man has created reservoirs. These may range in size from small ponds to lakes several miles long. Most of the major reservoirs do not contain *A. glabratus* as permanent populations, even though some are fed by infested headwater streams in the upland alluvial valleys or in the Caguana Peneplain areas. Occasionally a few specimens may be found in the headwater coves of such lakes. At least one reservoir (Carite) maintains a flourishing population of *A. glabratus* in its headwater coves. This lake seems to be unique in that it is situated entirely on a small upland alluviated valley. As it is also the oldest of the major reservoirs, it is possible that its ecological evolution has rendered it favourable to the snail. If so, the same thing may happen in the other major reservoirs within a few years.

The second type of artificial freshwater habitat is the small, temporary puddle, a few inches deep and a few feet in maximum diameter. Like the reservoirs, such puddles are also found in the other two major physiographical provinces. They seem to occur wherever the natural slope of the land has been artificially modified, as in road construction or in quarrying rock. Although *A. glabratus* is never present in these puddles, they do contain a small planorbid snail (*Tropicorbis circumlineatus* Shutt.) rarely found elsewhere.

A second major physiographical province is made up of the Tertiary limestone areas of the north and south coasts (see map). The south-coast area is very dry, karst topography is poorly developed and there are no permanent freshwater habitats. *A. glabratus* is not known there. The limestone area of the north coast is more humid, with very exaggerated karst topography. Most streams are underground. Those on the surface flow mostly on bedrock, with little rubble in the channels. They have very depauperate biotas. *A. glabratus* does not occur in them. Scattered throughout this area are numerous limestone sink ponds, in which the biota is varied and often abundant. *A. glabratus* is often present but no snails infected with *S. mansoni* have ever been found in them. The Tertiary limestone areas have the lowest incidence of bilharziasis in Puerto Rico. This may be due to the fact that the people use the streams and stored rainwater rather than the pond waters. Most of the ponds have marshy borders and the water is unattractive because of its dark colour.

The alluvial areas constitute the third major physiographical province (see map). Alluvium occurs at the mouths of all major streams, forming a more or less continuous belt around the coast. It also may extend several miles upstream, and thus dissect the two other major provinces. Moreover, several " upland alluviated valleys " occur in the oldland province. These are usually entirely disjunct from the coastal alluvium. In the alluvial areas there are many low-gradient streams, oxbow lakes, yazoo tributaries and para-estuarine marshes. All these types of habitat maintain *A. glabratus*. The alluvial province, both in the coastal regions and in the upland alluviated valleys, has the island's highest incidence of bilharziasis.

The natural filling of former marine lagoons along the north coast presents a graded ecological series of natural lakes. The Tirurones marsh, east of Arecibo (see map), has been almost converted into a fresh-water marsh, containing many square miles of habitat suitable for *A. glabratus*. Lake Tortuguero, farther to the east, has a biota characteristic of fresh water, but the water has a peculiar quality which may account for the absence of all molluscs. In the San Juan area, these lagoons are too brackish for established colonies of the snail. Lakes similar in appearance to these coastal lagoons, but of different origin, occur at the south-west corner of the Lajas Valley. Some of these contain the snail.

Drainage ditches in the wetter areas of the coastal alluvium provide excellent habitats for *A. glabratus*. Irrigation of sugar cane is practised only in the drier alluvial areas, chiefly in the south-west part of the island. Some irrigation aqueducts also contain *A. glabratus*. In the irrigated area, numerous " tanks ", or farm ponds, have been excavated for temporary storage of water. Some are filled from deep wells, others from the major irrigation aqueducts. *A. glabratus* is present in a few of the " tanks " closest to major aqueducts. That these populations are not well established is shown by the fact that juveniles are rare. Possibly these populations are maintained almost entirely by replenishment from the major aqueducts. In ponds more remote from the major aqueducts and in those fed by wells, large populations of another planorbid snail occur. These have been tentatively referred to as *Tropicorbis riisei*. Another species, *T. albicans*, is also present but is less abundant.

Stream Gradient as a Criterion for the Distribution of *A. glabratus* in Puerto Rico

The important foci of *S. mansoni* transmission in Puerto Rico are found in flowing waters. As noted above, *A. glabratus* is absent from high-gradient streams, but present in some streams of low gradient. " Steepness of gradient " is an arbitrary term, which needs more exact definition if practical use is to be made of it. Of course, in most streams slack-water reaches of low gradient alternate with riffles or falls of high gradient. The slack-water reaches become longer and the riffles or falls shorter and more gentle as one proceeds downstream. To determine the gradient length of every riffle, fall and slack-water reach is impractical.

In the present study, surveys were made at selected stations along many streams, the biota, water chemistry, general physiography and human use of the stream being noted. The findings were then correlated with stream gradient as determined from large-scale contour maps. It was found that a section of a stream about one kilometre in length is a practical unit, and this has been called the " standard reach ". The data suggest the hypothesis that established populations of *A. glabratus* do not occur in the main channel of streams which have a fall of more than 20 metres per kilometre, i.e., a gradient of 0.020 per standard reach. The snail may occur in occasional disjunct pools and small seepage tributaries along the steeper gradient reaches, but this criterion applies only to those populations which are established in the main channel of the stream. Actually, most standard reaches with a gradient as steep as 0.020 do not contain the snail, unless they are enriched with organic pollution. Alternating low-gradient and high-gradient reaches often occur because of the relationship between the two peneplains, the upland and lowland alluvium. While it may be expected that streams flowing on alluvium are of low gradient, this is not invariably the case. Regional uplift in recent geological time has resulted in the entrenching of the larger streams flowing on the alluvium. Some of them have cut completely through the alluvium and are again entrenched on the underlying bedrock. These may have gradients steeper than those favourable to *A. glabratus*. Extensive reaches of low gradient on many streams do not contain the snail, and this suggests that factors other than gradient may limit the occurrence of this species. A more extensive discussion of the relationship between stream gradient and the distribution of *A. glabratus* has been presented elsewhere (Harry & Cumbie, 1956b).

Fresh-water Biota of Puerto Rico Relative to the Distribution of *A. glabratus*

In studying the great variety of biotic assemblages which occur in the fresh waters of Puerto Rico, most attention was given to fish, crustacea, plants and molluscs. No single species was found which seems to affect appreciably the distribution of *A. glabratus*. Of course, it is possible that many species act together, through predation, parasitism and competition, to reduce the size of snail colonies. There was no indication that any of these natural enemies could be used in population control. Migratory birds, insects or amphibia may be responsible for the snail's introduction into new habitats, e.g., the limestone sink ponds.

Five species of trematodes, including *S. mansoni*, undergo parthenogenetic development in *A. glabratus*, and two additional species infect the snail only as metacercariae. Occasionally a fungus has been noted in the pulmonary cavity of this snail. A commensal microdrillid annelid (*Chaetogaster*?) is often abundant on the snail in nature, including those snails shedding cercariae of *S. mansoni*. There has been no direct evidence that any of these organisms would be of value in reducing the number of snails.

When guppies (*Lebistes reticulatus*) were introduced about a decade ago, it was suggested by Oliver-González (1946) that they might be useful in controlling the snail through predation on juveniles and eggs. The frequent association of large numbers of guppies and *A. glabratus* has not substantiated this hypothesis. Fish introduced from other areas include members of the Poeciliidae (*Gambusia* and two species of *Xiphophorus*), Siluridae (*Ictalurus* and *Ameiurus*) and several species of Centrarchidae. All these are often found in the natural habitats of *A. glabratus*, and the snail was also abundant in the fish hatchery ponds at Maricao.

Two species of large frogs, *Bufo marinus* and *Rana catesbiana*, have been introduced and are often found in the same waters as the snail. They are known to feed on it to a limited extent, but would not appear to be an effective means of control.

Several fresh-water shrimps of the families Atyidae and Palaemonidae, and the fresh-water crab *Epilobocera sinuatifrons*, occur in association with *A. glabratus*. To what extent these crustaceans feed on the snail is not known, but they are much esteemed as food by the local population. Entering the streams to catch them is undoubtedly one way in which man is exposed to cercariae.

All three species of leeches found in the island were associated with *A. glabratus*, but only one, *Helobdella punctolineata*, was widely distributed. It will decimate laboratory colonies of the snail, but does not seem to be an effective agent of control in nature.

Within the last four years, two species of ampullarid snails, *Pomacea* sp. and *Marisa cornuarietis*, have been introduced in Puerto Rico. These have produced enormous populations in limited habitats. Their use in excluding *A. glabratus* through competition and predation on the eggs has been proposed (Oliver-González et al., 1956 ; Watlington, 1955). No clear-cut instances of control by this means have been seen by the authors.

At about the same time, *Thiara granifera* was also introduced into Puerto Rico. The circumstances of its introduction are unknown. For two years after its discovery, this snail maintained a dense population in a single stream, but was not found in any other drainage system in the island. Within a period of a few months during the third year after its discovery, additional colonies appeared at many other places. Being ovo-viviparous and allegedly parthenogenetic (no males are known), it quickly produced abundant populations in the new habitats, but remained localized in those localities for at least a year after it was introduced. The peculiar pattern of this range extension suggests that *T. granifera* is also being distributed by man, which is unfortunate because this species is said to be the host of the lung fluke, *Paragonimus westermani*, in the Orient (Abbott, 1952).

An important problem is presented by the nine species of Planorbidae in Puerto Rico. A species of *Plesiophysa* and three species of *Drepanotrema* are easily differentiated from *A. glabratus*. However, larger specimens of a species of *Helisoma* and all sizes of two species of *Tropicorbis* are easily confused with *A. glabratus*, especially by those unfamiliar with molluscs. A third species of *Tropicorbis* occurs chiefly in temporary puddles, where *A. glabratus* is not found. It is easily distinguished from the latter on close examination.

One of the species easily confused with *A. glabratus*, *T. riisei*, occurs in great abundance in the south coastal area, frequently where *A. glabratus* is absent. This species may be closely related to, if not identical with, T. *havanensis* of Louisiana—a species which has been experimentally infected with *S. mansoni*—and *T. centimetralis* from Brazil, a species which is a known vector of bilharziasis. *T. riisei* has not been found naturally infected with *S. mansoni* in Puerto Rico, and the few attempts to infect it experimentally have been unsuccessful.

The tendency for particular biotic assemblages to be correlated with distinctive types of habitat suggests that water quality, in the broad sense, may be an important controlling factor. In the case of the biotic zonation which occurs in streams polluted by sewage and in the brackish littoral zone, this correlation is obvious. Recognizing these zones is useful to field workers studying the distribution of *A. glabratus*. This snail is encouraged by mild pollution, but inhibited by heavy pollution. It does not seem to occur in water subject to marine tidal fluctuation, even if the biotic assemblage is predominantly or entirely one characteristic of fresh water. However, it is frequently found in the less saline zones of the brackish marshes, areas characterized in Puerto Rico by the cat's-tail (*Typha*). In rare instances it has been found in association with mangrove, where these plants develop in situations not having tidal fluctuation.

A number of low-gradient streams of long reach do not contain *A. glabratus*, yet there is no obvious factor, such as shifting substrate or distinctive biota, which might explain the snail's absence. Some of these streams have abundant biotas, including abundant mollusc populations (*T. riisei*, *Physa cubensis*, freshwater Neritidæ) while others may be very oligotrophic. It is suspected that water quality, apart from pollution and brackishness, is a determining factor, but the details are unknown.

Life History of *A. glabratus* Relative to its Ecology

At any time of the year, all major stages of the life history (eggs, juveniles and adults) of *A. glabratus* can be found in some, though not all, habitats. Thus, there is no marked correlation between a particular stage of the life-cycle and the time of the year on a regional basis. Within a given habitat, however, there may be a very definite cycle of events: a period of several weeks when only adults are present is followed by a brief period of egg-laying and then by the appearance of juveniles, which increase in size until they merge with the adult population. The reason for this cyclic phenomenon is unknown. It may be repeated several times during the year, but does not seem to occur at the same time in every habitat.

When first hatched, *A. glabratus* has a shell of about one-half suture whorl size. During growth, the snail adds shell material to the aperture in such a way that the symmetry of the shell changes little, though the number of whorls may increase to a maximum of six and one-half suture whorls. In nature, however, few snails reach this size. The modal size of the adult snails in a given habitat is almost constant throughout the year, rarely varying as much as half a whorl. The same applies to a lesser extent to the maximum size of the adults. However, the modal size of the adults varies considerably in different habitats.

Populations of larger snails are found in some sluggish streams and marshes in the alluvial province and some limestone sink ponds. The populations of smaller adult snails were found only in streams with a gradient near the maximum at which the snail occurs. Populations of adult modal size intermediate between the extremes occurred in flowing and non-flowing waters. They were the most frequently encountered of the population types. No anatomical criterion other than size was found whereby these populations could be distinguished. This wide range of sizes possibly explains why so many species of *Australorbis* appear to have been distinguished in the Antilles, as well as on the South American mainland.

All three population types have been found naturally infected with *S. mansoni*. However, adult populations of larger modal size are rarely infected, possibly because they generally occur in habitats little frequented by man.

The snails naturally infected with *S. mansoni* are usually among the largest individuals of a given sample. Random sampling of snail populations in various parts of the island showed that the infection rates were nearly always less than 10% and usually less than 1%. When an exceptionally high rate (75-100%) was found it was always in populations of low density. These colonies are not always as dangerous as the infection rate indicates. Dense populations with a very low rate may have more infected snails and produce more cercariae per unit area. The chief danger of colonies of low density is that the few snails present are apt to be overlooked and the stream considered safe. Double infections of *S. mansoni* and one of the four other trematodes which infect *A. glabratus* are rare, but not unknown.

The Quality of Water Relative to the Distribution of *A. glabratus* in Puerto Rico

In appropriate circumstances certain aspects of water quality can be deduced with reasonable accuracy from the biota—for example, in the case of pollution and brackish zonation. However, the exact combination of the chemical and physical factors that make up the quality of the water cannot be studied without recourse to instruments and laboratory analysis. The possibility that the physico-chemical composition of the water plays an important role in limiting the snail's distribution should not be overlooked.

A. glabratus seems little affected by the amount of light which reaches its habitat. It is often found exposed to direct sunlight, and in habitats partially or well shaded.

The snail has also been found in a limestone sink pond which had a persistent high turbidity, due to the sediment stirred up by wading cattle. Temporary turbidity exists in many stream habitats at times of flushing, and this seems to have no marked effect on the snail. In most habitats where the snail is found, however, the water is usually clear.

A. glabratus is not known in waters more than one or two metres deep. The streams and ponds in Puerto Rico where it occurs are rarely more than one metre in depth. Deeper waters exist in the larger reservoirs, but dredging in several of these has failed to reveal the snail. Recently a deep reservoir (Carite) was found which does contain the snail in abundance in its headwater coves. The water quality of this remote lake is unknown and it has not been dredged.

The water temperature of the habitats of *A. glabratus* is generally within a few degrees of the air temperature. In some situations where the vegetation is dense and water currents minimal, surface temperatures may reach 34°C for several hours in the afternoon. Occasional habitats have a temperature of 21-23°C, chiefly in the early morning. This appears to be the maximum range, but in most habitats studied the temperature was usually between 25°C and 30°C. Diurnal variation within this narrow range seems to be greater than seasonal variation. Situations free from *A. glabratus* do not have temperatures beyond this range. Hence, temperature is believed not to be a limiting factor for this snail in Puerto Rico.

In water from some streams with heavy pollution and from the depths of some reservoirs no dissolved oxygen could be detected. *A. glabratus* has not been found in these waters. Although studies on dissolved oxygen are far from adequate, it seems unlikely that oxygen deficiency plays a major role in limiting the distribution of the snail, since most of the aquatic situations in Puerto Rico are shallow and well aerated.

The pH of fresh waters in Puerto Rico was found to range from 6.0 to 9.1. *A. glabratus* was found throughout this range. The hydrogen-ion concentration may vary widely within a few days in a given habitat. However, available data indicate that optimum habitats, where the snails are most abundant and persistent, are usually within the range of pH 7.0 to 8.0. The hydrogen-ion concentration is probably not a limiting factor in the distribution of the snail in Puerto Rico.

One of the most striking examples of a correlation between water quality and the distribution of *A. glabratus* is the absence of the snail from most waters containing small amounts of dissolved solids. The concentration of dissolved solids in the fresh waters in Puerto Rico ranges from about 50 to 3000 parts per million (p.p.m.). Optimum snail habitats usually have 150 to 500 p.p.m., but snails have been found in concentrations up to 3000 p.p.m. Only rarely are they found in waters which have concentrations consistently lower than 150 p.p.m. However, it may not be the lack of dissolved solids *per se* which accounts for the rarity of the snails in these waters. Snails will survive in the laboratory for several weeks in double-distilled water changed frequently, and with only very small amounts of lettuce provided as food. They can even be infected with *S. mansoni* under these conditions.

The bulk of the ions in the total dissolved solids of nearly all fresh waters consists of

$$HCO_3^-, CO_3^{--}, Cl^-, SO_4^{--}, Ca^{++}, Mg^{++}, Na^+ \text{ and } K^+.$$

In our study, analyses were not made for the last two. In general, the concentrations of all these ions are low in waters low in total dissolved solids, and correspondingly higher in waters with larger amounts of dissolved solids. *A. glabratus* has been found in waters having the maximum concentration of each of the major constituents for which an analysis was carried out. No significant correlation between the calcium-magnesium ratio and the distribution of the snail was found. In situations where the snail is present, the ratio of weak acids (bicarbonate and carbonate) to strong acids (chloride and sulfate) is less than 3 : 1, when the ions are expressed in equivalents per million. In the limestone streams, where the snail has not been found, the ratio is usually between 4 : 1 and 6 : 1. Possibly this ionic balance, or something varying with it, is responsible for the absence of the snail from streams on limestone.

The limestone sink ponds are insulated to varying degrees from the underlying bedrock by means of non-calcareous sediments derived from the bedrock and biota. Consequently, great variations in water quality occur in different ponds. The biota is similarly varied, and often very rich in species and individuals, in contrast to that of the limestone streams.

Of the minor constitutents which normally occur in fresh waters, analyses have been made only of copper and zinc. Analyses of 56 natural waters showed that the copper content ranged from 0.000 to 0.330 p.p.m. Snails were found in water that ranged from 0.000 to 0.018 p.p.m. of copper. With one exception, the seven waters having the highest concentrations of copper contained 150 p.p.m. or less of dissolved solids. The exception was a small stream on alluvium draining a copper ore deposit. Insufficient data are at hand for extensive generalization at present, but in the waters analysed thus far it appears that zinc occurs in greater amounts than copper. The possibility that copper or zinc might be the natural limiting agent is worthy of further study.

In the laboratory, short-term experiments (24 hours' duration) showed that zinc, copper, cadmium and silver in very low concentrations in distilled water have a distinctly deleterious effect on *A. glabratus*. Concentrations of these metals of less than 0.050 p.p.m. usually produced no reaction during the test period. Amounts of 0.050-0.100 p.p.m. produced a distinct distress syndrome, in which the snail was extended and showed feeble motion, but was unable to attach itself to the substrate. The tentacles became shortened and bulbed. If returned within a reasonable length of time to waters with low metal contents the distressed snails generally recovered. Concentrations of the metals of 1.0 p.p.m. or more in distilled water were generally fatal to the snails within a short time.

Some natural ores of copper, e.g., copper carbonates, have a detrimental effect on *A. glabratus*. Distinct distress reactions were produced in snails exposed to pulverized copper ores in distilled water. The ore in this state apparently acts as a contact or stomach poison, since no effect was produced in snails placed in distilled water in which these ores had been soaked for several days, or in snails which were exposed to large chunks of the ores that had been carefully washed to remove all small, loose granules. Even when the snails were not allowed to come in contact with it, metallic copper in distilled water produced a distinct distress syndrome.

When streams flush, the concentration of dissolved solids decreases. When they return to normal low stages, the concentration of some of the constituents may increase to a point where the precipitation of these toxic metallic ions occurs. In preliminary analyses of sediments of eight streams, the heavy metal content ranged from 0 to 40 p.p.m. All substrates from streams containing snails had less than 10 p.p.m. total heavy metal. The available data are too limited to establish a correlation, but there is some evidence that the chemical composition of the substrate is important. A more extensive account of water quality in relation to the distribution of *A. glabratus* in Puerto Rico has been presented elsewhere (Harry et al., 1957).

RÉSUMÉ

Les auteurs ont cherché à établir un rapport entre les facteurs écologiques et la répartition de *Australorbis glabratus*, hôte intermédiaire de *Schistosoma mansoni* à Porto Rico.

Le mollusque se développe de préférence dans les eaux courantes, non pas dans les rivières torrentueuses des terrains éruptifs de l'intérieur de l'île, mais dans les cours d'eau dont la dénivellation ne dépasse pas 20 m par km. Les zones alluvionnaires de la côte sont favorables en maints endroits à la vie du mollusque et constituent les principaux foyers de transmission de la bilharziose dans l'île. La lutte pour la vie, les prédateurs et les parasites limitent l'expansion des populations de *A. glabratus*, mais on ne connaît aucun ennemi capable d'assurer la lutte biologique contre ce mollusque. Des oiseaux migrateurs, des insectes et des amphibiens peuvent contribuer, d'autre part, à disperser l'espèce. Les variations d'opacité de l'eau, d'intensité de la lumière, de température ou de pH dans les eaux douces ne semblent pas affecter la répartition d'*A. glabratus*. La composition ionique de l'eau pourrait être un facteur limitant la répartition. On rencontre le mollusque dans les eaux dont la teneur en calcium, magnésium, bicarbonate, carbonate, chlorure et sulfate est la plus élevée. Une teneur en carbonates et bicarbonates relativement élevée par rapport à celle des chlorures et sulfates peut expliquer l'absence de ce mollusque dans certains habitats, tels que les ruisseaux des zones calcaires. La quantité d'oxygène dissous peut être un facteur limitatif dans les rivières très polluées

et le fond des réservoirs. On ne rencontre que rarement *A. glabratus* dans les eaux contenant moins de 150 p.p.m. de solides dissous. Ce dernier facteur peut cependant n'être pas déterminant, puisque l'on peut maintenir ces mollusques en laboratoire dans de l'eau bidistillée. Des concentrations de zinc, de cuivre ou de cadmium de 0,050-0,100 p.p.m. dans l'eau distillée exercent sur le mollusque un effet perturbateur très net, mais non létal. Des concentrations de 1,0 p.p.m. lui sont en général fatales.

REFERENCES

Abbott, R. T. (1952) *Proc. U.S. nat. Mus.*, **102**, 71

Harry, H. W. & Cumbie, B. G. (1956a) *Amer. J. trop. Med. Hyg.*, **5**, 742

Harry, H. W. & Cumbie, B. G. (1956b) *Amer. J. trop. Med. Hyg.*, **5**, 921

Harry, H. W., Cumbie, B. G. & Martínez de Jesús, J. (1957) *Amer J. trop. Med. Hyg.*, **6**, 313

Oliver-González, J. (1946) *Science*, **104**, 605

Oliver-González, J., Bauman, P. M. & Benenson, A. S. (1956) *Amer. J. trop. Med. Hyg.*, **5**, 290

Watlington, F. A. (1955) *Aquarium, Philad.*, p. 101